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COMPOSITIONAL REMOTE SENSING OF ICY PLANETS AND SATELLITES BEYOND JUPITER.

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Introduction: The peak of the solar energy distribution occurs at visual wavelengths and falls off rapidly in the infrared. This fact, improvements in infrared detector technology, and the low surface temperatures for most icy objects in the outer solar system have resulted in the bulk of telescopic and spacecraft observations being performed at visual and near-infrared wavelengths. Such observations, begun in the early 1970's and continuing to present, have provided compositional information regarding the surfaces of the satellites of Saturn and Uranus, Neptune's moon Triton, Pluto, Pluto's moon Charon, Centaur objects, and Kuiper belt objects. Because the incident sunlight penetrates the surface and interacts with the materials present there, the measured reflected sunlight contains information regarding the surface materials, and the ratio of the reflected to incident sunlight provides a mechanism of identifying the materials that are present.

Fink and Sill [1] and *Roush* [2] present the reflectance spectra of various ices. An initial identification of the species present on solar system objects can be provided by comparison with these laboratory spectra. More detailed information, such as relative abundances grain sizes of surface constituents, requires more detailed models.

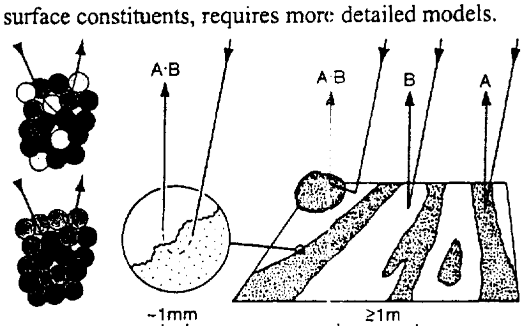

Figure 1. *The cartoon on the right [3] illustrates spatial mixing of spectra where the reflectance is dominated by photons encountering individual materials. Along some pathways a component of intimate mixing remains. The upper-left cartoon illustrates intimate spectral mixing where the reflectance is dominated by photons that encounter several materials. The lower-left cartoon illustrates intimate spectral mixing with a surface layer.*

Various mathematical models are used to characterize the chemical and physical nature of the surfaces under investigation. They can also be used to extend the results of laboratory studies to different mixtures and particle sizes that are not directly investigated.

Spatial mixtures (see Fig. 1) describe photons reflected from the surface that are dominated by interactions with individual surface species. The total surface reflectance is given by $R_T = X_1 \times R_1 + X_2 \times R_2 + \cdots + X_n \times R_r$, where X is the areal extent, and R the reflectance of each component, respectively, and it is required that $\Sigma X_i = 1$. Examples of these types of surfaces are individual rocks or outcrops.

In intimate, or "granular", mixtures (see Fig. 1) the surface reflectance is a non-linear function of the reflectances of each component because a photon encounters several grains, due to multiple scattering, before exiting the surface. Examples are individual minerals that are contained in rocks and planetary soils and regoliths.

A series of papers summarized in *Hapke* [4] developed an approximation to the intimate mixture case allowi the reflectance to be calculated from the optical properties of the surface components. This important contribution allowed the quantitative estimation of the relative abundances and grain sizes of surface components and, given the appropriate observations, some information regarding the surface physical structure. Table 1 summarizes some of these efforts applied to objects in the outer solar system.

Table 1. Outer Solar System Surfaces Modeled Using Hapke Theory

Object	Property	Reference
Europa	T	5
Ganymede	T	5
Callisto	T, C	5, [6-8]
Enceladus	T	5
Tethys	T	5
Dione	T, C	5, 9
Rhea	T, C	5, 9
Iapetus	T, C	5, [10-11]
Rings	T	5
Miranda	C	12
Ariel	T, C	5, 13
Umbriel	T	5
Titania	T, C	5, [13-14]
Oberon	T,C	5, [13-14]
Triton	T, C	[15-16], [17-19]
Pluto	T, C	20, [21-25]
Charon	T, C	26, [23,26-30]
Trans-Neptune objects	C	[31-33]

T= Temperature, C= composition